Wavelength-shifting Reflector Foils in Liquid Argon Neutrino Detectors

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Abstract

We propose using wavelength-shifter-coated reflective surfaces (e.g. foils) as new components in LArTPC neutrino detectors. Adding these foils as passive element of Light Detection Systems (LDS) would greatly improve the uniformity of light collection which translates into improved calorimetric reconstruction, triggering and timing resolution. It also enables a new feature in LArTPCs, namely positional resolution in the drift direction, which can improve background rejection from cosmic events or enable reading out only a fraction of the detector, provided two light-detector types are used. In this document we list the ideas and possibilities of using large scale WLS-coated surfaces in liquid argon neutrino detectors.

Liquid Argon Time Projection Chamber (LArTPC) detectors when used to detect neutrinos use primarily ionization signals to reconstruct neutrino interactions. Liquid argon is also a prolific scintillator and the light it emits is used as the primary signal channel in Dark Matter experiments. The light is emitted at 128 nm, in the vacuum ultra violet (VUV) range, and so it must be wavelength-shifted to visible wavelengths to enable its detection with conventional light detectors. DarkSide and DEAP experiments [1, 2] have shown that scintillation light in liquid argon can be used for energy reconstruction at energy scales much lower than those needed for typical accelerator or even astrophysical neutrinos, provided the light yield is high enough. Applications of scintillation light to reconstructing neutrino interactions are still in development in parallel with the development of new methods of collecting scintillation light in these large scale detectors.

We propose to use reflective surfaces, e.g. di-electric foils, coated with wavelength-shifting (WLS) compounds (TPB, PEN) to enhance the light collection in future large-scale neutrino detectors such as DUNE. Installing such components in a detector increases the overall performance of light collection and its uniformity in the detector. This leads to a better handle on calorimetric reconstruction but also enables new applications of scintillation light in neutrino detection.

Applications of Scintillation Light in Neutrino LArTPCs

The full potential of scintillation light in LArTPC neutrino detectors has still not been tapped. Scintillation light can be used to enhance the performance of LAr neutrino detectors in several ways: timing and triggering, tagging of decays, energy reconstruction, position reconstruction and cosmic rejection.

Timing and Trigger

Scintillation light travels significantly faster than the drift ionization charge. It can therefore be used to determine the time an event occurred, which can be used in triggering, as in the ICARUS [3] and MicroBooNE [4] detectors.

Decay Tagging

The much faster nature of scintillation light enables tagging decays happening in a LArTPC. Tagging Michel electrons from muon decays has been proposed [5] and demonstrated: [6]. Tagging shorter decays times may prove to be more difficult due to the timing structure of the light.

Calorimetry

For a given energy deposition, the ionization charge and scintillation light are anti-correlated. A good collection of both of these channels improves the overall energy resolution of neutrino events, particularly at supernova and solar neutrino energies, as demonstrated by the LArIAT experiment with Michel electrons [6].

Position Reconstruction and Background Rejection

MicroBooNE [4] has pioneered the use of scintillation light to find the position of an event in the TPC. This enables rejecting cosmic ray backgrounds when multiple events are present in the TPC.

More Uniform Light Collection using WLS-coated Reflectors

The standard light collection in LArTPCs usually involves sensitive light collection devices, usually coated with a WLS, behind the wire planes. This results in a non-uniform light collection due to geometric effects and Rayleigh scattering, see blue points in the Figure, which can affect all of the applications of scintillation light mentioned before. To determine calorimetry, apply a trigger, etc. a correction must be made for the position of the scintillation light emission in the detector.

We propose to install wavelength-shifter coated reflective surfaces on the cathode of large scale neutrino detectors, such as DUNE-Single Phase. Alternatively, they could be installed on the anode, as in the case of the vertical drift design [7] where the light detectors would be installed on the cathode. Such surfaces would then recover the VUV light impinging on them, by wavelength-shifting it to visible wavelengths and reflecting it towards the light detectors near the opposite end of the TPC. See red points in the Figure. The overall effect (black points in the Figure) is an increase the uniformity of light collection and an improvement of its overall performance, especially for events furthest from the light detectors.

Benefits of Uniform Light Collection

Triggering: Uniform light collection throughout the detector allows translating the light collected by the detectors into energy without having to correct for x-position. This means a trigger could be set to effectively reject or select events in a certain energy range.
Calorimetry: Uniform light collection throughout the detector makes it also easier to use scintillation light for calorimetric reconstruction. In a non-uniform system, events occurring close to the cathode may register as a scintillation signal with very few photons due to the long distance, making the returns from using scintillation light limited.
Drift Position Reconstruction: The light arriving from the cathode is already wavelength-shifted, meaning that if two different types of detectors are installed at behind the wire planes, with at least one sensitive to only VUV or only visible light, we can use this extra information to locate the scintillation light event in the drift direction. This can be done either using timing information, or by the ratio of the direct VUV signal to the re-emitted visible signal. This could be used to either improve background rejection capabilities or implement readout of only a fraction of the drift time potentially significantly reducing data throughput of the detector.

Implementation

Apart from having been used in dark matter detectors, WLS-coated reflector plates have been realized in the LArIAT test-beam experiment[8] where TPB-evaporated sheets were installed first on the field-cage walls and in the final run on the cathode, being sandwiched in a metal mesh. A similar approach will be used by SBND, where the CPA will host 64 double-sided di-electric reflector panels, also evaporated with TPB, sandwiched inside of a metallic mesh. For larger scale detectors PEN films [9] has been proposed an alternative wavelength-shifter, due to its relative ease in coating large surfaces. Work is ongoing to find a PEN grade with wavelength-shifting performance resembling that of TPB. Small scale LArTPCs with cathodes coated with di-electric reflective foils, coated both with either PEN or TPB have been successfully operated showing that such a solution is also feasible.

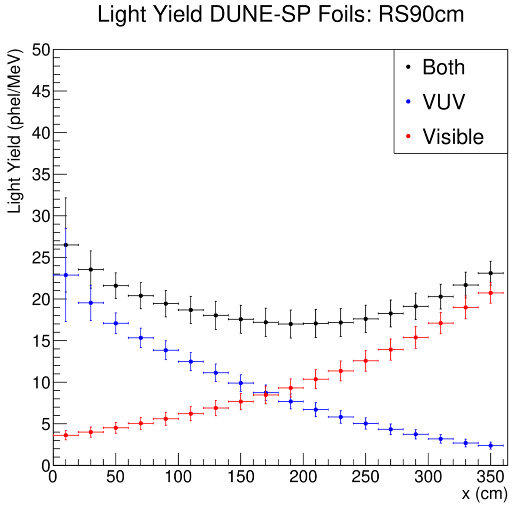

Figure 1: Simulated Light Yield in a DUNE-like single-phase detector as function of drift distance. Blue points represent direct VUV light detected by WLS detectors. Red points represent light wavelength-shifted and reflected off of the cathode and arriving at the detectors at visible wavelengths. Black points are the sum of red and blue points and exhibit a much larger uniformity along the drift than the two components alone. Assumed 3.5% QE efficiency of light detectors, 90 cm Rayleigh scattering length, and that 30% of the light detectors are kept sensitive to only the visible component.

Conclusion

We propose using WLS-coated reflector foils in large-scale liquid argon time projection chamber neutrino detectors, such as DUNE. This solution will enhance the light collection capability of these detectors as well increasing the uniformity. This will introduce new possibilities for implementing scintillation light triggers, particularly for lower energy astro-physical neutrinos coming from supernovae or the Sun, improve the calorimetric reconstruction and introduce the possibility of reconstructing the position of an event in the drift using scintillation light.

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